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Excel simulation of parallel DC/DC converters with mutual capacity

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***Abstract* — The paper contains calculated results of transient analysis for parallel DC/DC converters. The calculations are conducted in Excel, where they are also rendered in the clear charts. The charts provide good overview how the parallel converters work and which parameter is vital for proper functioning. Consequently certain requirements for parallel co-operation of more DC/DC converters are declared at the end.**

***Keywords* — current-sharing, DC/DC converter, MS Excel, transient analysis**

I. Introduction

The switch-mode power supplies (SMPS) are recently very popular because of their high effectivity, lower cost, smaller size and lower weight compared to conventional linear power supplies. The essential and vital part of every SMPS is DC/DC converter. The mostly used DC/DC converter in SMPS is buck (step-down) converter. This type of converter is also used for analyze in this article [1], [2], [3], [4].

The use of one DC/DC converter can easily reach its limits, when high power output is needed. A parallel interconnection of more converters can be appropriate and promising solution. However, more converters connected in parallel are mostly problematic and some special arrangements are necessary. The load of every converter needs to be equal to each other. In other words, the level of their output currents needs to be equal or very similar. It is the basic principle and a requirement for proper functioning. This property and at the same time basic requirement is well known as *current-sharing*, thus converters need to have the same share on the overall amount of output current. When this is not satisfied, one of the converters may be very dominant and subsequently excessively stressed. Consequently, it leads to faults and the whole system is not functional and does not deliver the required amount of output power [1], [2], [5], [6].

Further chapters contain comparison of calculated results performed in Excel for several different parameters of DC/DC converters. The calculations in the Excel are based on the transient analysis, which was conducted earlier and its results were published in the article [7].

II. Topology and Verification

There needs to be realized PC simulation in trustworthy system and compare it to Excel to increase the credibility of its results. Thus the PC simulation is realized in OrCAD and its PSpice module with the same parameters as in Excel. However in OrCAD is used model of LM2576 integrated regulator, which cannot be completely simulated in Excel, so the results cannot be the same, but they can be very similar with minor variations. In the parallel connection of two DC/DC conveters is used mutual capacitor at the output. In the figure 1 can be seen scheme of the system from OrCAD, the same topology (mutual capacitor) is also simulated in Excel calculations.

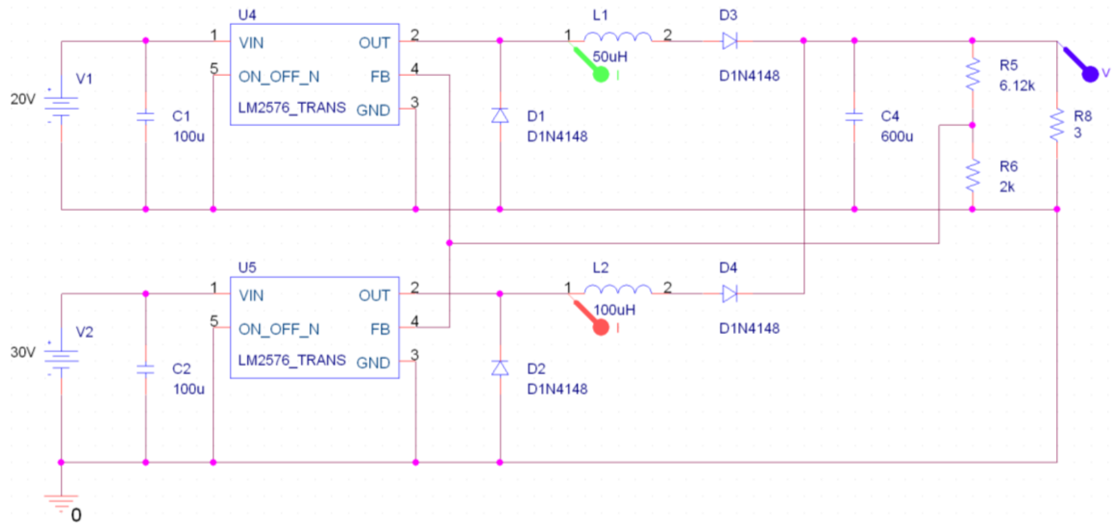

Fig. 1 Scheme of the parallel connected DC/DC converters with the mutual capacitor in OrCAD

Both converters are connected together through diodes (D_3, D_4). These diodes ensure inductors stays separated and converters dont influence each other. In this case power supplies and inductors are different (V_1, V_2, L_1, L_2,), while output capacitor is mutual (C_4). The simulation result from PSpice is in the figure 2.

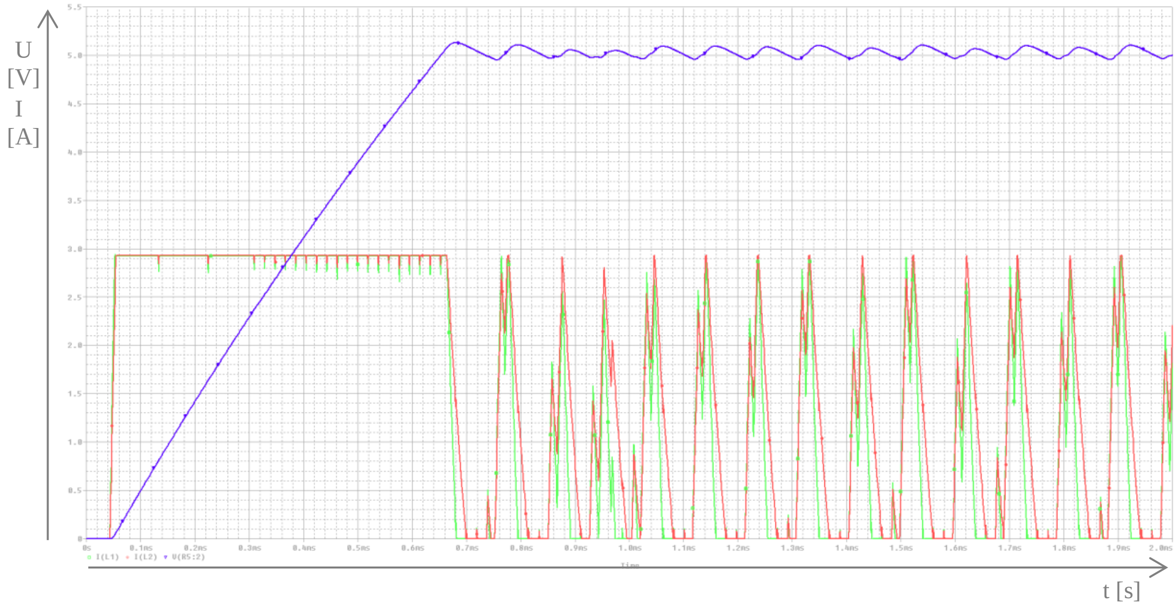

Fig. 2 Simulation results of the parallel DC/DC converters with mutual capacitor from PSpice

As can be seen in the figure 1 according to color probes, blue curve represents output voltage, green is current through first converter and red is current through second converter. Output voltage is set to 5V by the resistive divider. Both currents through converters don't exceed 3A.

Parameters which can be set for both converters in Excel are: power supply, frequency of switching, inductance (separately for both converters), capacity (one mutual for both converters), load resistivity, internal parasitic resistivity of converter, requested value of output voltage, maximum value of current and time constant Δt. The time constant Δt represents time step of every single calculation in transient analysis. The smaller the constant Δt the more precise the calculation (and also the graph) is. However smaller constant Δt requires more calculations (more lines in Excel). At the this time Excel has 17000 lines for calculations of a few ms of voltage and current. Cells with yellow background color represents parameters which should be set by the user. Cells with no background color are filled automatically and user should not change their value. In the figure 3 is screen of Excel with filled parameters and with two graphs for both converters.

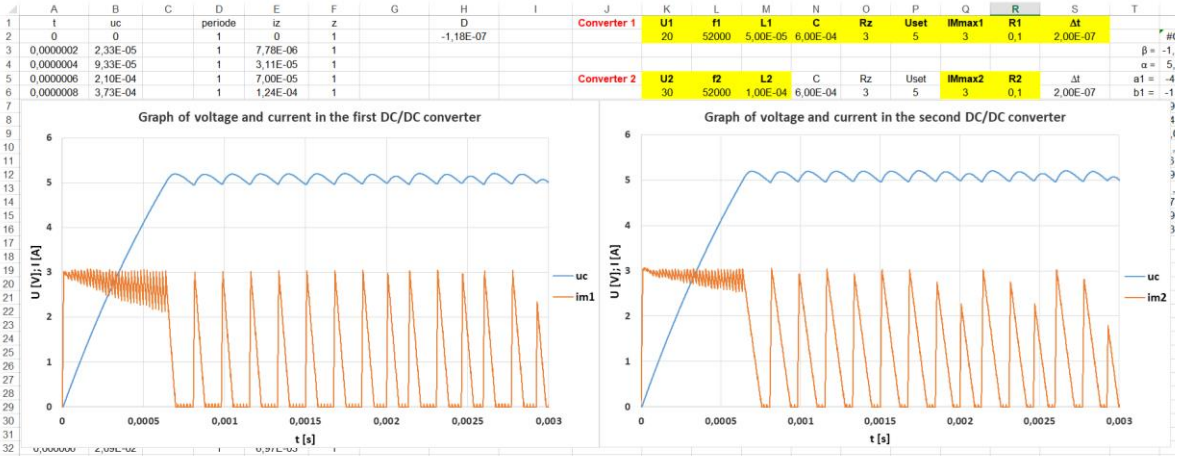

Fig. 3 Calculated results of the parallel DC/DC converters with mutual capacitor from MS Excel

In the figure 3 can be seen very similar course of observed voltage and currents. Voltage ripple, rise time and pulsed currents are almost the same in comparison to results from PSpice simulation. This fact proves that Excel model based on transient analysis is quite precise and can be used for further analysis. The next chapter contains investigation of how particular parameters influence output characteristics of parallel connected converters with help of the Excel model.

III. REQUIREMENTS FOR PARALLEL CONNECTION

For the possibility of the comparison in the first case will be all parameters the same in both converters. The maximum current in both converters is set to 3A, because PSpice model which was tested in previous chapter also has current limit at this value. The results from Excel can be seen in the figure 4.

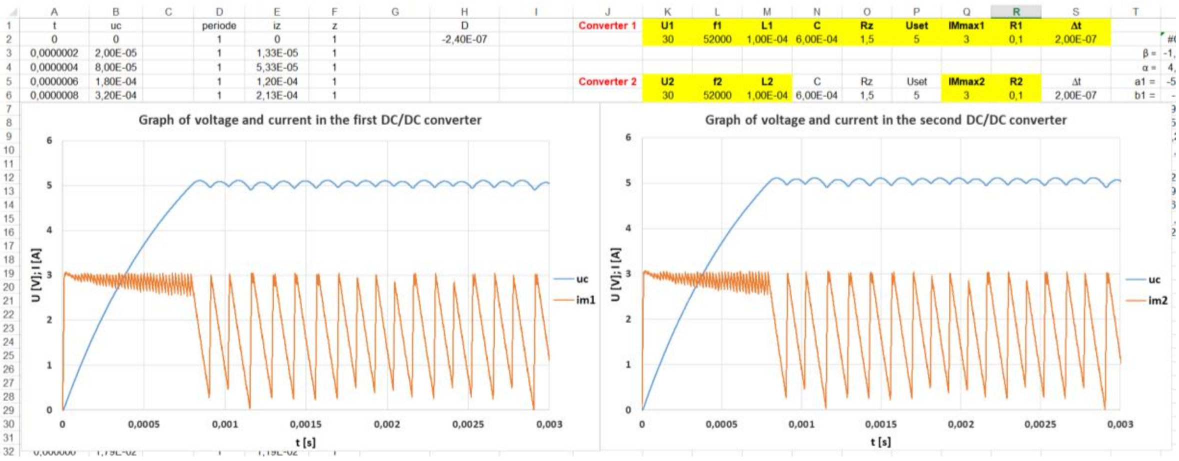

Fig. 4 Calculated Excel results for same parameters of both converters

The output characteristics are identical in this case. For parallel co-working of more converters their currents need to be the same or with minor difference only. So this case is ideal, but there is only little chance that two converters will have all parameters the same. Now can be tested how each particular parameter influence the balance between currents (current-sharing). In the figure 5 is Excel calculation where first converter has lower supply voltage (U_1=20V, U_1=30V).

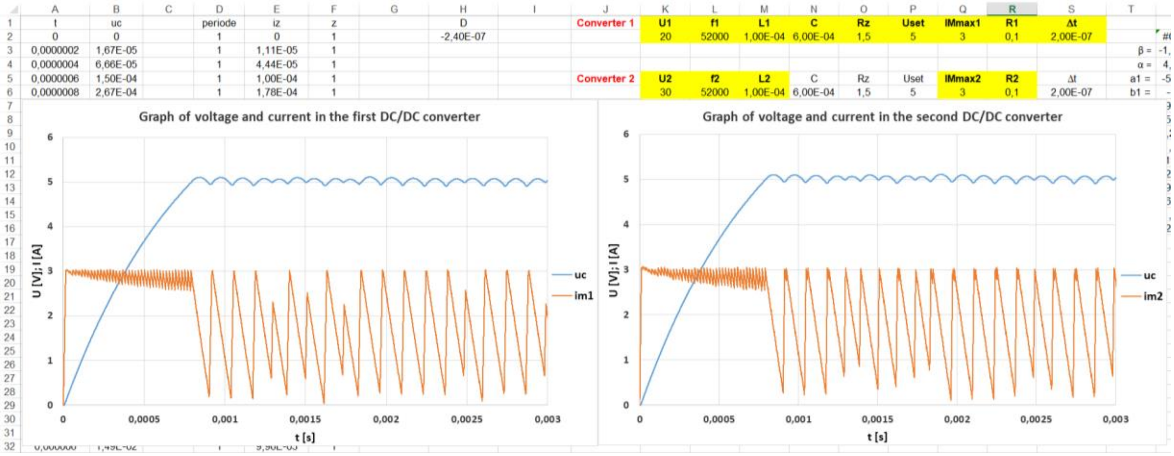

Fig. 5 Calculated Excel results for different supply voltage values of both converters

As can be seen in the figure 5, different supply voltage can have negative influence on current-sharing. The difference between currents is almost 1A in some switching periods. Next tested parameter is the frequency of switching. Calculated results in Excel are in the figure 6, where the first converter has switching frequency f_1=20kHz, while the second has f_2=52kHz.

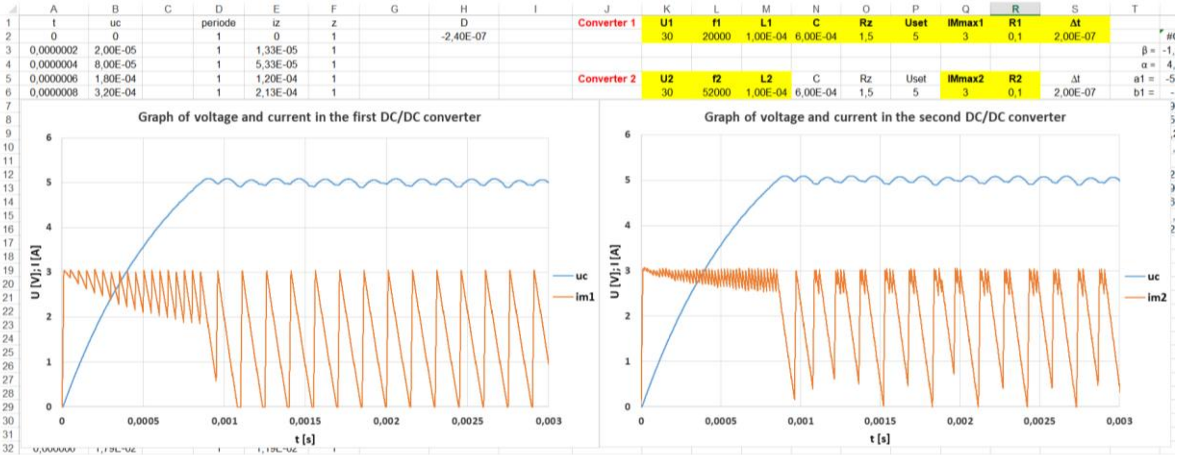

Fig. 6 Calculated Excel results for different switching frequencies of both converters

The difference between the currents is pretty significant in this case. Using of two converters with different switching frequency in parallel connection can cause serious troubles in reliable functionality. In the figure 7 are results for different inductances.

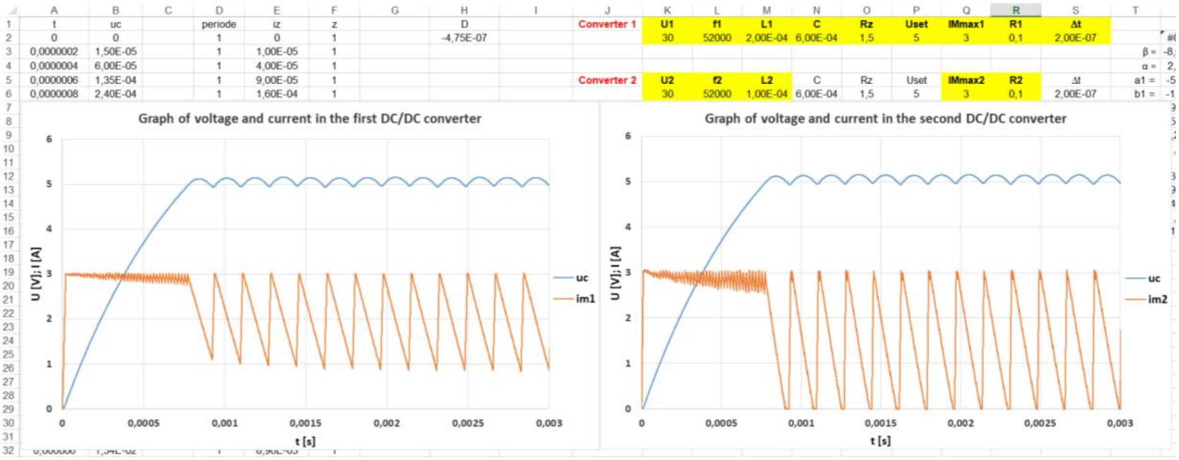

Fig. 7 Calculated Excel results for different inductances of both converters

According to results showed in the figure 7, the difference in inductances has quite significant negative impact on the current-sharing. While the first converter has 100µH higher inductance the amplitude of current pulses is 1A lower than for the second converter.

The capacity is mutual in this case, so it cant have negative impact on parallel connection and current-sharing. However in the figure 8 can be seen how the capacity influence output characteristics.

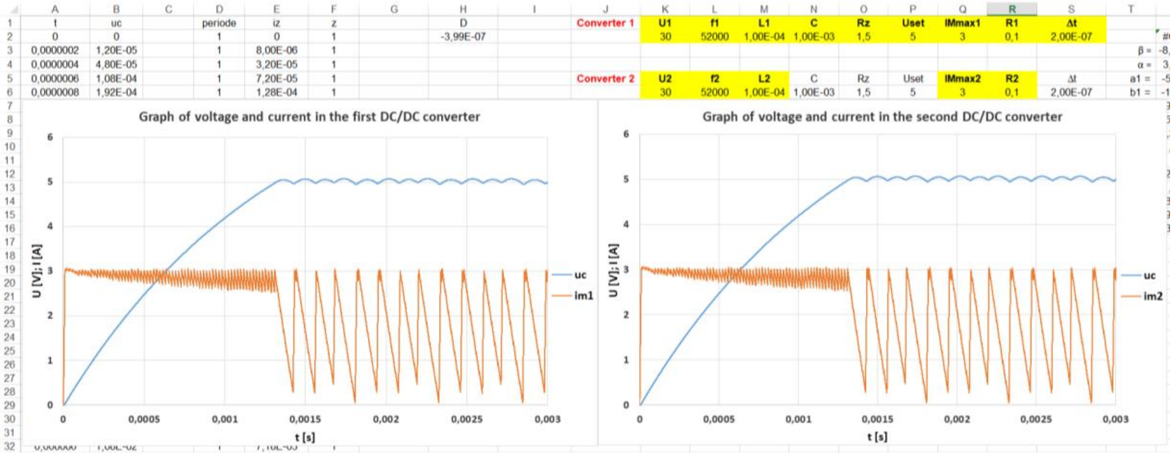

Fig. 8 Calculated Excel results for changed mutual capacity

The capacity was increased from 600µF to 1000µF. As a consequence the rise time is approximately 0,5ms longer and voltage ripple is lower, so the output voltage is more smooth.

IV. Conclusion

The Excel model using transient analysis is very useful tool for researching a DC/DC converter possibilities as well as possibilities of their parallel co-working. The advantage of Excel model are instant changes visible in output graphs according to changing of input parameters. The results based on transient analysis are universal, thanks to that they are applicable on buck DC/DC converters in general.

The results published in this article shows, that converters connected in parallel should have the same power supply voltage, they should be controlled by the same switching frequency and at last but not least they should have the same or very simillar value of inductance. The value of mutual capacity has no influence on current-sharing in this case. In general can be said, that converters should have implemented some form of current regulation for reliable functionality in parallel connection.

Acknowledgment

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